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TITLE: NACA 0015 Data [Nominally Two-Dimensional]

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22E(2) NACA 0015 DATA (NOMINALLY TWO-DIMENSIONAL)

INTRODUCTION

The tests described were carried out in the University of Glasgow's 'Handley Page' wind tunnel, which is a closed-return, low-speed type with a 2.13m x 1.61m octagonal working section. The model span was 1.61m, and its construction was of a fibre glass skin filled with an epoxy foam bonded to an aluminium spar. The model was pitched about the quarter chord by a linear hydraulic actuator and crank mechanism. The actuator was a Unidyne 907/1 type with a dynamic thrust of 6.1kN controlled by a MOOG 76 series 450 servo valve. Thirty Kulite 093-5 PSI G ultra-miniature pressure transducers were installed below the skin in a removable pod at the centre-span of the model. The transducers were of the vented gauge type with one side open, via tubes, to ambient pressure outside the tunnel. Each transducer was fitted with a temperature compensation module to minimize changes in the zero-offset and sensitivity. Model incidence was determined using an angular potentiometer geared to the model's main spar. This provided feedback to the hydraulic actuator control system and the angle of incidence signal for the data recording system. The model incidence waveform was provided by a PC fitted with an ANALOGUE DEVICES RT 1815 input/ output board. The dynamic pressure in the working section was determined by measuring the difference between the static pressure in the working section, just upstream of the model leading edge, and the static pressure in the settling chamber. These pressure tappings were connected to a Furness FC012 micromanometer which provided an analogue signal for the data acquisition module.

Two NACA 0015 models were tested, namely a "full" chord, low aspect ratio model, and a "short" chord, high aspect ratio model. The former, of 0.55m chord was tested as part of the research programme at the time to investigate the dynamic stall over a family of aerofoil profile shapes. The latter model, of 0.275m chord was tested with a view to an investigation of the dynamic stall vortex convection speed anomaly (reference 2, 4 and 10). Each model was instrumented with 30 pressure transducers placed symmetrically over the upper and lower surfaces at the mid-span of the model. Four motion types were considered, namely static, ramp-up, ramp-down and oscillatory (sinusoidal). The models were both rotated about the quarter chord point. In static tests each model was positioned at an incidence of -1° and pitched to 30° and back down to -1° in 1° increments allowing a settling time for each new incidence. For the ramp-tests the models were pitched over a preset arc at a constant pitch rate. At low pitch rates excellent ramp-profiles were obtained, but at higher pitch rates acceleration and deceleration of the model produced non-linearities. For ramp tests each test case was performed 5 times, and the data were phase averaged to produce the results presented here. For the sinusoidal tests 10 cycles of motion were recorded, and again the data were phase averaged

FORMULARY

1 General Description of model

1.1	Designation	Full Chord	Model 5
		Short Chord	Model 12
1.2	Type	Nominally two-dimensional	
1.3	Derivation	Not applicable	
1.4	Additional remarks	None	
1.5	References	9	

2 Model Geometry

2.1	Planform	Nominally two-dimensional	
2.2	Aspect ratio	Full Chord	2.93
		Short Chord	5.86
2.3	Leading edge sweep	None	
2.4	Trailing edge sweep	None	
2.5	Taper ratio	No Taper	
2.6	Twist	No Twist	
2.7	Wing centreline chord	Full Chord	0.55m
		Short Chord	0.275m
2.8	Semi-span of model	0.805m	
2.9	Area of planform	Full Chord	$0.8855m^2$ gross wing area
		Short Chord	$0.443m^2$ gross wing area

2.10	Location of reference sections and definition of profiles	NACA 0015 profile nominal ± 0.05mm accuracy
2.11	Lofting procedure between reference sections	Constant section
2.12	Form of wing-body junction	None
2.13	Form of wing tip	Not applicable
2.14	Control surface details	None
2.15	Additional remarks	None
2.16	References	9

3 Wind Tunnel

3.1	Designation	University of Glasgow 'Handley-Page'
3.2	Type of tunnel	Closed section, closed return, atmospheric
3.3	Test section dimensions	2.13m (width) x 1.61m (height) x (length)
3.4	Type of roof and floor	Closed – vented at downstream end of working section
3.5	Type of side walls	Closed - vented at downstream end of working section
3.6	Ventilation geometry	60 rectangular slots (0.028m x0.055m) on floor, roof and walls downstream of working section. 13 rectangular slots (0.028m x 0.105m) at same section on angled surfaces.
3.7	Thickness of side wall boundary layer	Unknown
3.8	Thickness of boundary layers at roof and floor	Unknown
3.9	Method of measuring velocity	Working section and settling chamber static pressure tappings related to wind tunnel speed calibration
3.10	Flow angularity	Not available
3.11	Uniformity of velocity over test section	Dynamic pressure constant to within 1% over a $1.5m^2$ reference plane normal to the flow axis in the working section
3.12	Sources and levels of noise or turbulence in empty tunnel	Not available
3.13	Tunnel resonances	Not available
3.14	Additional remarks	None
3.15	References on tunnel	8

4 Model motion

4.1	General description	Four motion types: Static, Linear Ramp Up, Linear Ramp Down and Sinusoidal. All incidence variations about quarter chord.
4.2	Natural frequencies and normal modes of model and support system	Not available

5 Test Conditions

5.1	Model planform area/tunnel area	Full Chord	0.258
		Short Chord	0.129
5.2	Model span/tunnel height	0.756	
5.3	Blockage	Full Chord	Function of angle of attack 3.9% - 16.6%
		Short Chord	Function of angle of attack 1.9% - 8.4%
5.4	Position of model in tunnel	Vertical on tunnel centre-line. Mounted through floor. (see Fig. 3)	
5.5	Range of velocities	45 m/s to 55 m/s	
5.6	Range of tunnel total pressure	Approximately 102.5kPa to 103kPa	
5.7	Range of tunnel total temperature	Approximately 293K to 306K	
5.8	Range of model steady or mean incidence	-5° to 42°	
5.9	Definition of model incidence	Deviation of chord line from tunnel centreline	
5.10	Position of transition, if free	Not available	

5.11	Position and type of trip, if transition fixed	Full Chord	None
		Short Chord	When applied, grit layer from leading edge to 2% chord on upper and lower surfaces.
5.12	Flow instabilities during tests	Not available	
5.13	Changes to mean shape of model due to steady aerodynamic load	Not available	
5.14	Additional remarks	None	
5.15	References describing tests	9	

6 Measurements and Observations

6.1	Steady pressures for the mean conditions	Yes
6.2	Steady pressures for small changes from the mean conditions	No
6.3	Quasi-steady pressures	No
6.4	Unsteady pressures	Yes
6.5	Steady section forces for the mean conditions by integration of pressures	Yes
6.6	Steady section forces for small changes from the mean conditions by integration	No
6.7	Quasi-steady section forces by integration	No
6.8	Unsteady section forces by integration	Yes
6.9	Measurement of actual motion at points of model	No
6.10	Observation or measurement of boundary layer properties	No
6.11	Visualisation of surface flow	No
6.12	Visualisation of shock wave movements	No
6.13	Additional remarks	None

7 Instrumentation

7.1	Steady pressure		
7.1.1	Position of orifices spanwise and chordwise	Chordwise only. See Table 6.	
7.1.2	Type of measuring system	Full Chord	30 Individual Kulite sensors mounted close to wing surface connected to DEC MINC parallel channel data acquisition system.
		Short Chord	30 Individual Kulite sensors mounted close to wing surface connected to Bakker Electronics BE256 parallel channel data acquisition system.
7.2	Unsteady pressure		
7.2.1	Position of orifices spanwise and chordwise	Chordwise only. See Table 6.	
7.2.2	Diameter of orifices	1.0mm	
7.2.3	Type of measuring system	Full Chord	30 individual Kulite sensors mounted close to wing surface connected to DEC MINC parallel channel data acquisition system.
		Short Chord	Individual Kulite sensors mounted close to wing surface connected to Bakker Electronics BE256 parallel channel data acquisition system.
7.2.4	Type of transducers	Kulite CJQH-187 differential	
7.2.5	Principle and accuracy of calibration	Steady state sensitivity from applied reference and calibration procedures. Accuracy as stated by manufacturer.	
7.3	Model motion		
7.3.1	Method of measuring motion reference co-ordinate	Quarter chord location specified by manufacture	

7.3.2	Method of determining spatial mode of motion	Feedback from potentiometer geared to shaft.	
7.3.3	Accuracy of measured motion	0.1°	
7.4	Processing of unsteady measurements		
7.4.1	Method of acquiring and processing measurements	Full Chord	30 individual Kulite sensors mounted close to wing surface connected to parallel channel DEC MINC sample and hold modules. Signal conditioning modules on each individual channel. Gain and offset removal manual. Acquired data downloaded to PC.
		Short Chord	30 individual Kulite sensors mounted close to wing surface connected to parallel channel Bakker Electonics BE256 sample and hold modules. Signal conditioning modules on each individual channel. Gain and offset removal manual. Acquired data downloaded to PC.
7.4.2	Type of analysis	Phase averaging of cycles. Five cycles for ramp function tests, ten cycles for oscillatory function tests.	
7.4.3	Unsteady pressure quantities obtained and accuracies achieved	Basic unsteady pressure signal. Cycle repeatability variable depending on amplitude and reduced pitch rate.	
7.4.4	Method of integration to obtain forces	Trapezoidal rule	
7.5	Additional remarks	None	
7.6	References on techniques	None	

8 Data presentation

8.1	Test cases for which data could be made available	Full Chord	Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. Tests cover a range of reduced pitch rate, mean incidence and amplitude and reduced frequency. In total 479 test cases. All incidence variations about quarter chord.
		Short Chord	Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. Tests cover a range of reduced pitch rate, mean incidence and amplitude and reduced frequency. In addition ramp and oscillatory tests with leading edge sand strip. In total 240 test cases. All incidence variations about quarter chord.
8.2	Test cases for which data are included in this document	Full Chord	Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. 10 test cases as detailed in Table 7. A series of plots are also presented which are illustrative of the data supplied in electronic form. Figure 5 shows a sample upper surface pressure distributions, C_n, C_m and incidence histories for a ramp-up case.
		Short Chord	Four motion types: Static, Linear Ramp Up and Linear Ramp Down and Sinusoidal. 16 test cases as detailed in Table 8. A series of plots are also presented which are illustrative of the data supplied in electronic form. Figure 6 shows a sample upper surface pressure distributions, C_n, C_m and incidence history for a ramp-up case.
8.3	Steady pressures	For static case	
8.4	Quasi-steady or steady perturbation pressures	No	
8.5	Unsteady pressures	For all dynamic cases	
8.6	Steady forces or moments	For static case	
8.7	Quasi-steady or unsteady perturbation forces	No	

8.8	Unsteady forces and moments	For all dynamic cases
8.9	Other forms in which data could be made available	None
8.10	Reference giving other representations of data	N/A

9 Comments on data

9.1	Accuracy	
9.1.1	Mach number	±0.5%
9.1.2	Steady incidence	±0.1°
9.1.3	Reduced frequency	±0.5%
9.1.4	Steady pressure coefficients	±0.5%
9.1.5	Steady pressure derivatives	Not estimated
9.1.6	Unsteady pressure coefficients	±0.5%
9.2	Sensitivity to small changes of parameter	N/A
9.3	Non-linearities	N/A
9.4	Influence of tunnel total pressure	Not examined
9.5	Effects on data of uncertainty, or variation, in mode of model motion	N/A
9.6	Wall interference corrections	None
9.7	Other relevant tests on same model	None
9.8	Relevant tests on other models of nominally the same shapes	None
9.9	Any remarks relevant to comparison between experiment and theory	None
9.10	Additional remarks	The electronic data supplied with this report comprises two file types. The first type of file contains the transducer co-ordinates. There is only one file of this type, and it is identified by the name naca0015_xducers.dat. The second type contains the test data. The first 128 parameters are the run information data (described in table 5), and the remaining parameters are blocks each comprising the dynamic pressure, pressure coefficients (30 values) and angle of incidence. The number of blocks depends upon the motion type. A MATLAB program to read in the data is listed in appendix B. The pressure transducer locations correspond to the order contained in the file naca0015_xducers.dat, which is the same as in table 6.
9.11	References on discussion of data	2, 5, 4, 10

10 Personal contact for further information

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